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ZOOM ANAMORPHIC EYEPIECE EVALUATION

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ZOOM ANAMORPHIC EYEPIECE EVALUATION

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ABSTRACT

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[redacted] investigated the effectiveness of adding zoom anamorphic eyepieces to the IOIC Stereometric Comparison Viewer (SCV). These eyepieces, replacing those presently used on the SCV, provided an adjustable affine transformation. This transformation was purported to allow stereo observation of photography which otherwise would be unusable. The investigation revealed that the action of these eyepieces, while improving the esthetic quality of the stereoscopic illusion, did not enable the recovery of any non-fusable imagery of the type occasionally encountered in the IOIC. Provisioning of the anamorphic eyepieces was not recommended for the SCV.

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I. INTRODUCTION

This report was prepared by [redacted] under Item 1(f) of Contract [redacted] "Development and Evaluation of IOIC Improvements". Item 1(f), proposed by [redacted] Letter 65CL 1657, dated 15 April 1965, concerns the evaluation of the effectiveness of adding partially rectifying zoom anamorphic eyepieces to the IOIC Stereometric Comparison Viewer (SCV). Contact was made with the [redacted] on 7 July 1966 to obtain a pair of these eyepieces for test. They were made available to [redacted] 10 March 1967, on a loan basis.

The effectiveness of the eyepieces was measured relative to the current task performance of photo interpreters using the SCV in the IOIC. Generally this involved the overall utilization of photographic inputs, and in particular, the recovery of otherwise non-fuseable stereo photography resulting from excessive or distorted image relief. Excessive or distorted image relief is the normal outcome of certain photograph and viewer geometric situations, and is covered in detail in this report.

Prior to the subjective evaluation, an investigation was conducted to determine the compatibility between the SCV and the anamorphic eyepieces. It was found that, mechanically, the eyepieces could be installed on the SCV in less than one minute. Their added length elevated the observation point to such a degree that a stool had to be substituted for the normal SCV chair. It was also difficult to physically constrain the barrel of the anamorphic eyepieces relative to the SCV frame. As a result the calibrated adjustment dials on the eyepiece could not be employed to their fullest utility. None of these mechanical problems however were severe enough to preclude a good test of the eyepiece. They will have to be corrected however, before any field use can be considered.

The applicability of IOIC image input to the type of image rectification offered by the anamorphic eyepiece, revealed good compliance. This was tested by the use of a stereo image formation model, devised as part of this study program. The model revealed that the camera imagery, routinely employed in the SCV, would provide photographic situations applicable for eyepiece evaluation. For example, the RA-5C reconnaissance aircraft provides 3.15 and 18 inch focal length panoramic, and 6 and 1.75 inch focal length vertical and oblique serial frame photography, of high acuity. This photo equipment operates at all altitudes and thereby provides a broad spectrum of image geometry and format.

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Expanding upon the information revealed by the study model, photography exhibiting the required image formats, scales, and subject matter was selected from the RA-5C film file for the test program. The stereo image formation model, which is described in detail under a separate heading in this report, rests upon the basic difference between direct human observation of a stereo situation and that obtained via an aerial camera and stereoscope. From this frame of reference the SCV is not significantly different from other existing stereoscopes. To elaborate, stereoscopic illusions, recreating the three dimensional situation existing beneath a photographic aircraft, have been used for some time for mapping and mensuration purposes. This illusion, formed by observing overlapping photography through a stereoscope, does not exactly duplicate the three dimensional situation as seen first hand by an observer. The distortion of depth and shape of objects, commonly seen in stereoscopes, results from this discrepancy. The distortion, existing in the stereo illusion can become so severe under certain photographic situations, that stereo fusion cannot be formed in the mind of an operator. Instead, two separate images are seen. When this happens the photography has lost it's stereo significance, and either the photographic mission must be rerun or stereoscopic analysis abandoned.

The special anamorphic eyepiece was developed to provide the capability of giving a controllable single coordinate image rectification. This rectification offers the potential of alleviating the above problem. This device, called a Zoom Anamorphic Eyepiece, can be employed in any stereoscope having a standard eyepiece socket, by performing a simple mechanical exchange.

The ability of the eyepiece to accomplish its purported objectives was tested by two photo interpreters and an opto-mechanical engineer. Examples of photographic images, representing various degrees of fusion difficulty, were used in the test.

A single zoom anamorphic eyepiece is shown in Figure 1. An analytical evaluation of the image rectification performed by this eyepiece is given in Appendix 1. Equations (1) and (2), taken from this appendix, expresses the location of any image point P(X,Y) as it is transposed by the anamorphic action of the eyepieces.

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$$X_s = (a - 1) \left[X \cos \Theta + Y \sin \Theta \right] \cos \Theta + X \qquad (1)$$

$$Y_s = (a - 1) \left[X \cos \Theta + Y \sin \Theta \right] \sin \Theta + Y \qquad (2)$$

Where:

- X, Y = Coordinates of P in the original image.
- X_s, Y_s = Coordinates of P_s in the stretched image.
- a = Numerical value of image stretch.
- Θ = Angular alignment of the stretch coordinate to the original image X coordinate.

The adjustment provisions of the zoom anamorphic eyepiece is shown in Figure 2(A). Using equations (1) and (2), examples of the effects produced by these adjustments are illustrated in Figure 2(B). Plotted is the loci of points defining a square existing in the input image, and the loci of the corresponding output points. The plot is repeated for four values of image stretch (a) and stretch alignment angle (Θ). It will be noted that the stretch always expands about the center of the optical system. This gives the effect of a lateral displacement as well as stretch for any object lying off the axis.

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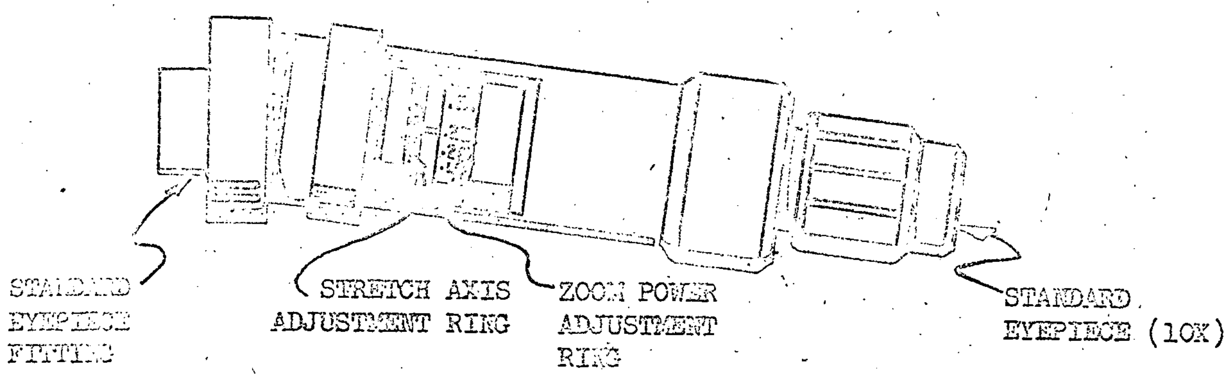
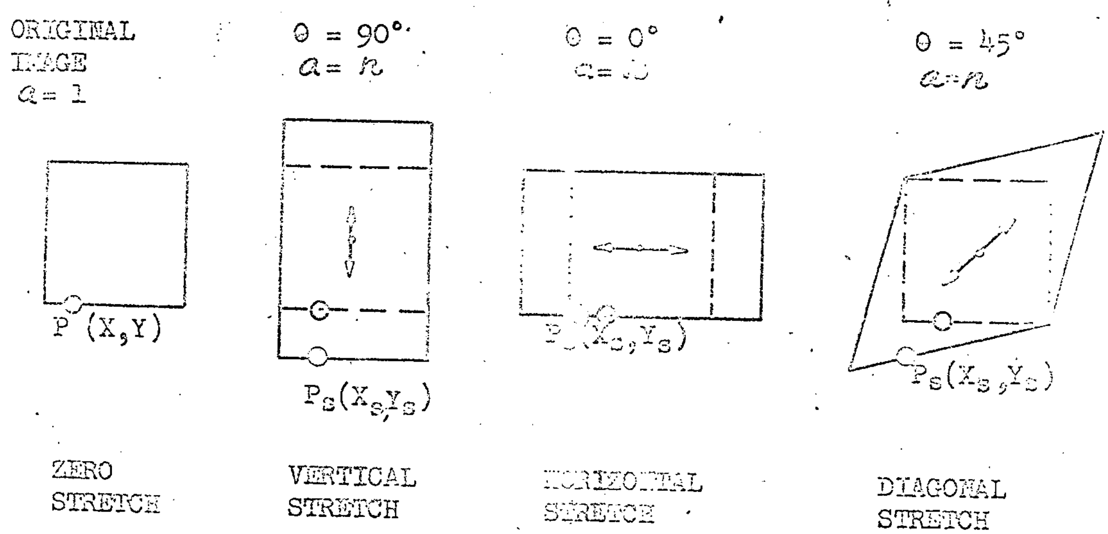


(A) ZOOM ANAMORPHIC ADJUSTMENT PROVISIONS



(B) TYPICAL IMAGE MANIPULATIONS

ANAMORPHIC EYEPIECE IMAGE MANIPULATIONS

FIGURE 2

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II. PRELIMINARY EVALUATION

The anamorphic zoom eyepiece was evaluated as part of the SCV stereo optic system, and considered not only the existing stereo capability of the viewer, but also the proposed stereo planar mensuration and height mensuration improvements. The analysis included the following factors:

1. The physiological effect of anamorphic zoom on the ability to obtain stereo fusion.

2. The opto-mechanical effect of the anamorphic zoom system on mensuration accuracy.

3. The optical effect of the anamorphic zoom on the ability to see.

4. The human factors consequences of the physical installation.

Physiological Considerations

Real Life Stereo vision is made possible when an object is observed from the slightly different angles produced as a result of the separation of the eyes. The amount of image disparity between the right and left eye, under this situation, provides a mental clue to object depth. This disparity is called parallax. The amount of eye rotation (convergence) necessary to place the object of interest at the proper points on both retinas is called squint. The amount of eye muscle exertion to produce squint is thought to be used by the brain as an input to determine the distance between the object and the observer. The eye-brain uses both the distance and depth clues to understand the real life depth situation.

The eye-brain mechanism for producing stereo vision is under intensive study by many investigators. All factors of this mechanism are not completely understood, but it is obvious that the parallax and squint are major contributors to the stereo sensation. It is also obvious that any departure from the normal real life ocular image geometry produces discrepancies tending to confuse the stereo comprehension process. Practically all reconnaissance stereo recording-viewing systems introduce unnatural geometric imate distortions. If severe enough, these distortions noticeably affect the ability of the observer to obtain stereo fusion.

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The anamorphic eyepiece is intended to provide a convenient method of producing a linear single coordinate image rectification. This rectification, (sometimes called an affine transformation), has the potential of reducing the observed image distortion. This in turn could mean the possible salvage of otherwise unusable stereo imagery. On the basis of this, an analysis was conducted to determine the nature of stereoscopic image geometry distortion, the type of photography most apt to reveal it, and the optimum application of a zoom anamorphic eyepiece for stereo restitution.

Opto-Mechanical Considerations

The anamorphic zoom eyepiece, was evaluated in terms of the overall performance change when used as an accessory to the Stereometric Comparison Viewer (SCV). In its present configuration, the SCV provides for stereo observation of imagery, after it has first been identified via a self-contained rear screen projection system. The SCV stereoscope system does not have stereo mensuration capabilities now, but this capability is proposed. The effects of anamorphic zoom on the accuracy of mensuration was therefore considered. The major concern, the effect of anamorphic stretch upon the ability to align a mensuration reticle accurately on a photographic image, was easily resolved for this analysis. The anamorphic eyepiece, being the first element in the optic train, affects the image and the reticle equally, expanding symmetrically about the reticle axis. Therefore, the film distances measured are unaffected by anamorphic image manipulation. Secondary effects, resulting from any operator confusion produced by the distortion of the reticle shape, were not considered. This is a factor of reticle design and beyond the scope of this analysis.

Optical Considerations

The optical effects of the anamorphic zoom eyepieces were not analyzed prior to the tests on the SCV. It was obvious that any addition to the optical train would introduce optical performance degradations. The decision was made to determine the extent of these degradations to a degree commensurate with the projected usefulness of the eyepiece.

Human Factors Considerations

The human factor considerations of time, precision, and excellence of SCV task performance was considered in light of the addition of the anamorphic eyepieces. It was found that the eyepieces in no way disturbed the non-stereo SCV functions, in that they did not obstruct the vision or body movements of the operator. The eyepieces raised the operators eye position approximately eight inches, however, necessitating the substitution of a stool for the normal SCV chair when performing stereo operations. There appears no practical way to circumvent this problem, even if the eyepieces were reconfigured for a custom fit to the SCV. A finite amount of optical distance is required to achieve the anamorphic effect, and adding angles and folds to the eyepiece shape, to allow a more comfortable eye location, would destroy the inherent versatility of the present design. Two solutions are evident; either redesign the SCV stereoscope, integrating the zoom anamorphics, or provide a stool. From the standpoint of applicability, it was evident that the anamorphic capability is potentially useful for only a small percentage of the time. One eyepiece set could therefore be shared between several operator stations. The features of compactness, versatility and simplicity, now inherent in the design, should be retained to allow convenient storage within the IOIC.

Certain minor control operational inconveniences were also evident, stemming from the fact that the anamorphic eyepieces were not designed for the SCV. The adjustment of the magnitude and direction of the zoom is achieved by two calibrated axial rings, located on the barrel of the eyepiece. Adjustment of either of these controls was a two handed operation on the SCV test installation; one hand being employed to constrain the barrel from rotating. This arrangement was workable, particularly when visual cues were employed for regulating the adjustments. In a production application however, the SCV eyepiece mounting sockets would be modified to allow the existing anamorphic eyepiece clamping arrangement to function. This would constrain the barrel satisfactorily. Once provisions are made for locking the barrel position, the calibrated adjustment rings could be employed to facilitate the manipulation of the stereo image geometry.

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In order to use the time saving potential of the calibration adjustment rings, some method must be made available to inform the operator of the proper settings. Fortunately the IOIC already contains the basic sensing and software capability for this. Implementing the required additional calculation capability will require the development of operational procedures and additional software to handle the anamorphic image mathematical manipulations.

In general the human factor problems, discovered during the evaluation program, could be solved by routine engineering methods. In most cases these problems existed because the SCV was not specifically considered during the design and development of the eyepieces.

Summary of Preliminary Evaluation

The preliminary evaluation indicated that the change, produced in the physiological aspects of SCV stereo viewing was the most inflexible aspect of the evaluation. The opto-mechanical, optical, and human factor problems were not of a gross magnitude and are amenable to routine engineering modifications. However the physiological consequences of image manipulation are complex and subjective. A detailed evaluation was therefore directed to a better understanding of the stereo geometric image errors as they applied to the SCV utilization of the zoom anamorphic eyepiece. In this way a more thorough understanding of the application of the eyepiece to the task of interpretation of the various IOIC photography was obtained.

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III. DETAIL EVALUATION

Sources of Stereo Image Distortion

The present and proposed SCV stereo systems operate in the same general manner. Stereo photography is provided by vertical and oblique serial frame cameras and side to side sweeping panoramic (PAN) cameras. This photography is viewed with zoom optics held normal to the photographic plane. This arrangement, although standard, produces geometric distortions, some of which are beneficial.

In most cases these distortions are evident if the stereo displays are viewed objectively. Typically, height is accentuated, verticality of tall objects relative to their base is violated, and rectilinearity of objects is distorted. As pointed out, these are visual effects, which lie outside the mensuration apparatus. However, as these distortions become more and more removed from the natural stereo situation, the observer has greater difficulty in accpeting and fusing the images. The source of these distortions is illustrated in Figure 3.

Figure 3 is a graphic illustration of the difference between natural human stereo observation of an object, and indirect observation via a camera and stereo viewer.

Four situation are depicted:

1. Natural Stereo - The human observing an object (in stereo) as he would naturally.

2. Camera Stereo - The object image situation of 1. above, is duplicated, but scaled to represent a photographic aircraft-object relationship. Camera shutter actuation points (a) and (b) represent locations at which the images would have to be recorded to duplicate the stereo geometry (A to R_1) of natural observations. Actual reconnaissance photography is an optimization of efficient area coverage and stereo overlap requirements. The usual 60 percent overlap results in a base line to slant range ratio $\left(\frac{B}{R_2}\right)$ which is out of scale with the natural ratio $\left(\frac{A}{R_1}\right)$.

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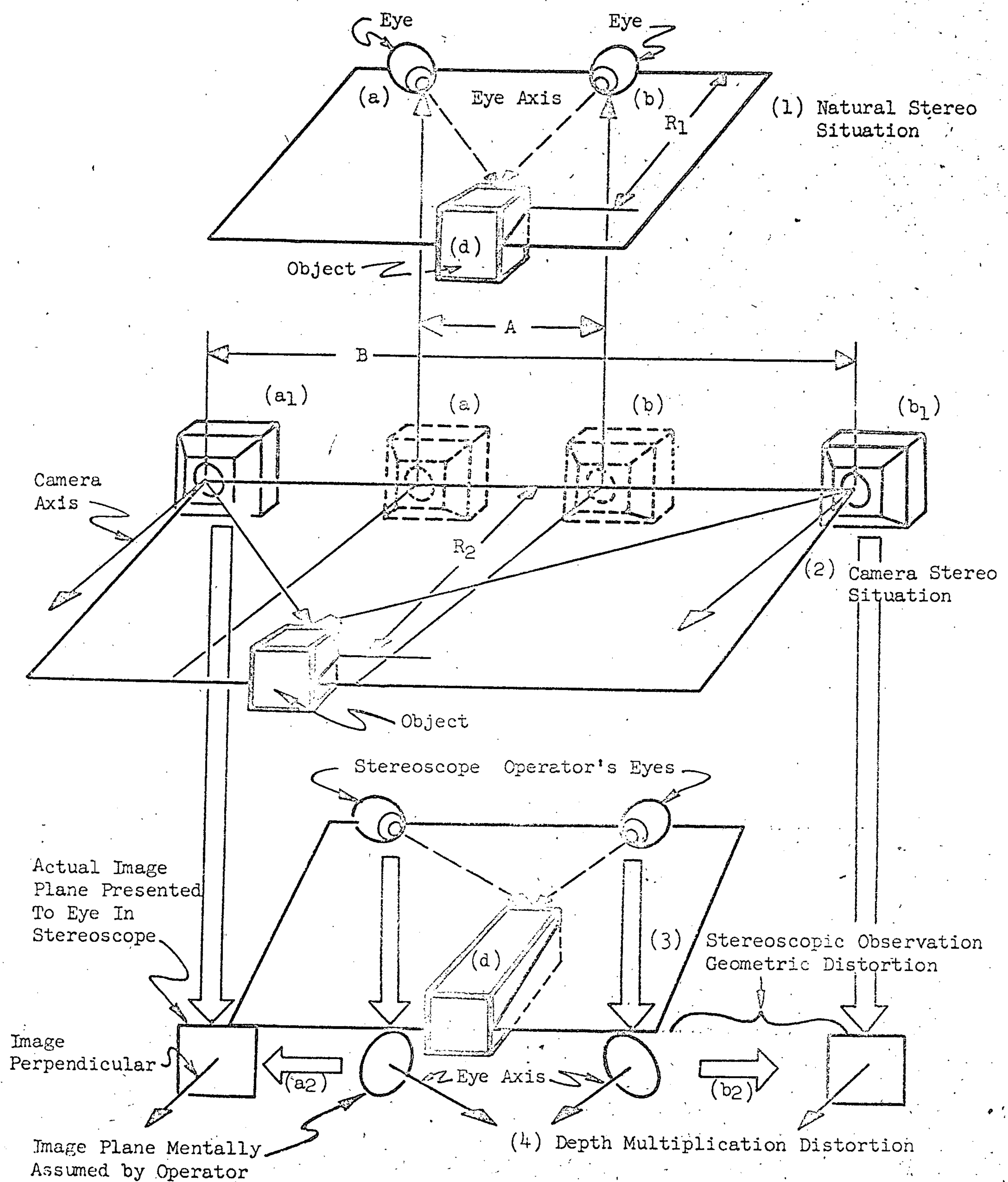

RELATIONSHIP OF NATURAL STEREO OBSERVATION
TO STEREOSCOPIC OBSERVATION

Figure 3

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3. Stereoscopic Observation Geometric Distortion - The image geometry (perspective) is dependent upon the coordinate relationship of the optical sensor (camera or eye) to the object scene. A serial frame camera axis is usually pointed at a fixed angle relative to the aircraft flight path. Conversely, the eyes rotate so that a common point of fixation is centrally located on each retina. The resulting disparity between the natural coordinates of the eye and that of a camera is illustrated at points (a_2) and (b_2).

4. Depth Multiplication Distortion - The disproportionate stereo base line produced by camera positions (a_1) and (b_1) yields a proportional stereo depth distortion to the human observer. This effect is illustrated at (d). The camera-optic system produces the effect of greatly extended eye separation, which the eye-brain interprets as extended depth. Depth, being sensed as slant range from the observer, produces the effect of accentuated height in vertical photography and a stretching and deepening of objects in oblique photography.

Method of Evaluation

Considerable latitude existed as to the type of analysis to be employed in examining the source stereo distortion, and its effects on stereo vision. Owing to the many coordinate transformations and dependent variables, a rigorous mathematical solution was rejected. As a general search of the available literature did not reveal data applicable to this problem, a graphical solution was chosen as the most practical analytical method. Key objectives to this decision were:

a. Keep the analytical effort commensurate with the experiment control which would be available.
b. Provide the maximum visualization for the experiment, since human subjective judgement would be the major control of the experiment.
c. Give the maximum insight to secondary effects, and the eyepiece adjustments to compensate for them.

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Graphic Solution

The graphical analysis approaches the stereo image distortion problem in terms of specific planes of interest. Figure 4 defines these. Two planes are depicted, the first plane, the "Plane Containing the Object and Camera", exists at the target at the time the imagery is taken. The position of the eyes in this plane represents the image recording situation necessary to produce "natural stereo". The second plane, the "Plane of Stereoscopic Observation", represents the viewing situation in the SCV stereoscope, with the stereo optics held normal to the film. In this frame of reference the contribution of squint to stereoscopic distortion was considered.

Stereoscopic squint can be achieved by several different methods, depending upon the optical design of the stereoscope. Ideally, the squint during stereoscopic observation ($\alpha_1 + \gamma_1$) will match the normal squint of the observer when viewing an object at approximately 10 inches (standard design distance). The angles ($\alpha + \gamma$) and ($\alpha_1 + \gamma_1$) therefore are usually 10 to 14 degrees, based on the standard interpupillary distance. Actually, however the photo interpreter may adjust ($\alpha_1 + \gamma_1$) to equal any angle between 0 and 14 degrees. This angle will be mainly dependent upon the actual focal length to which the stereoscope is adjusted, the tolerance of the individual to abnormal squint, and the details of the optic design. Usually older operators prefer eye focal length adjustments longer than 10 inches. In this case, the natural matching squint will be correspondingly less. Since, in all cases the angles involved are small, stereoscopic squint has a direct but relatively insignificant effect upon stereo distortion.

The disparity between natural visual and stereoscopic visual geometry is further illustrated in Figure 5. This figure defines the left eye geometry of Figure 4 in greater detail. Depicted is the image created by points ACD on an object lying in the left foreground of a reconnaissance airplane. Image plane (3) represents the position and rotation of the left eye (or camera image for the left eye), if the natural relative parallax geometry is to be maintained. Image plane (4) represents a vertical camera operating in a typical image overlap condition. If an eye were placed in this position it would rotate to give image plane (5). If image plane (5) were transmitted to the stereoscopic eye without further distortion, true image depth multiplication would occur and would be proportional to the separation of images (3) and (5).

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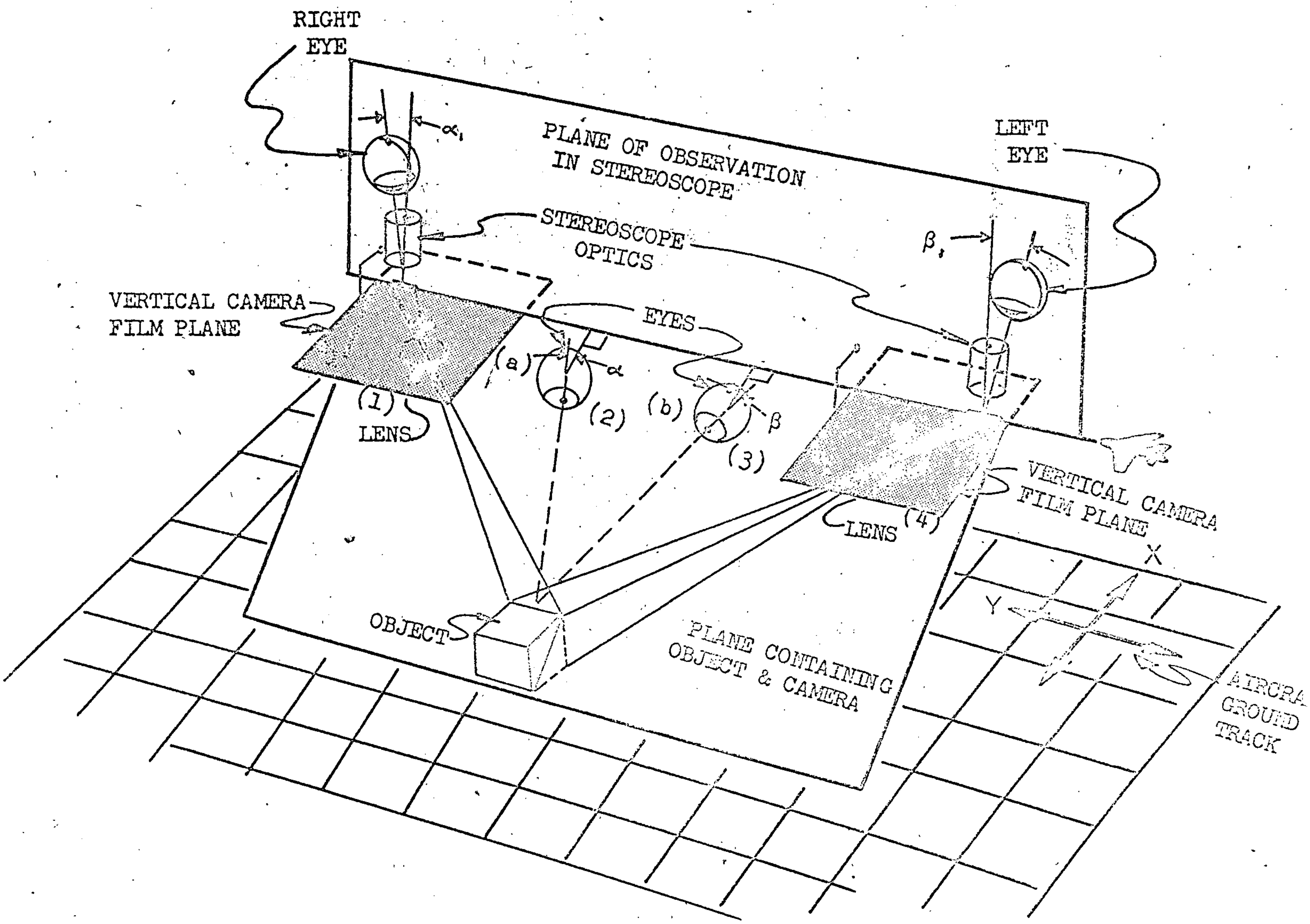

OVERALL PLAN OF STEREO
IMAGE DISTORTION ANALYSIS

FIGURE 4.

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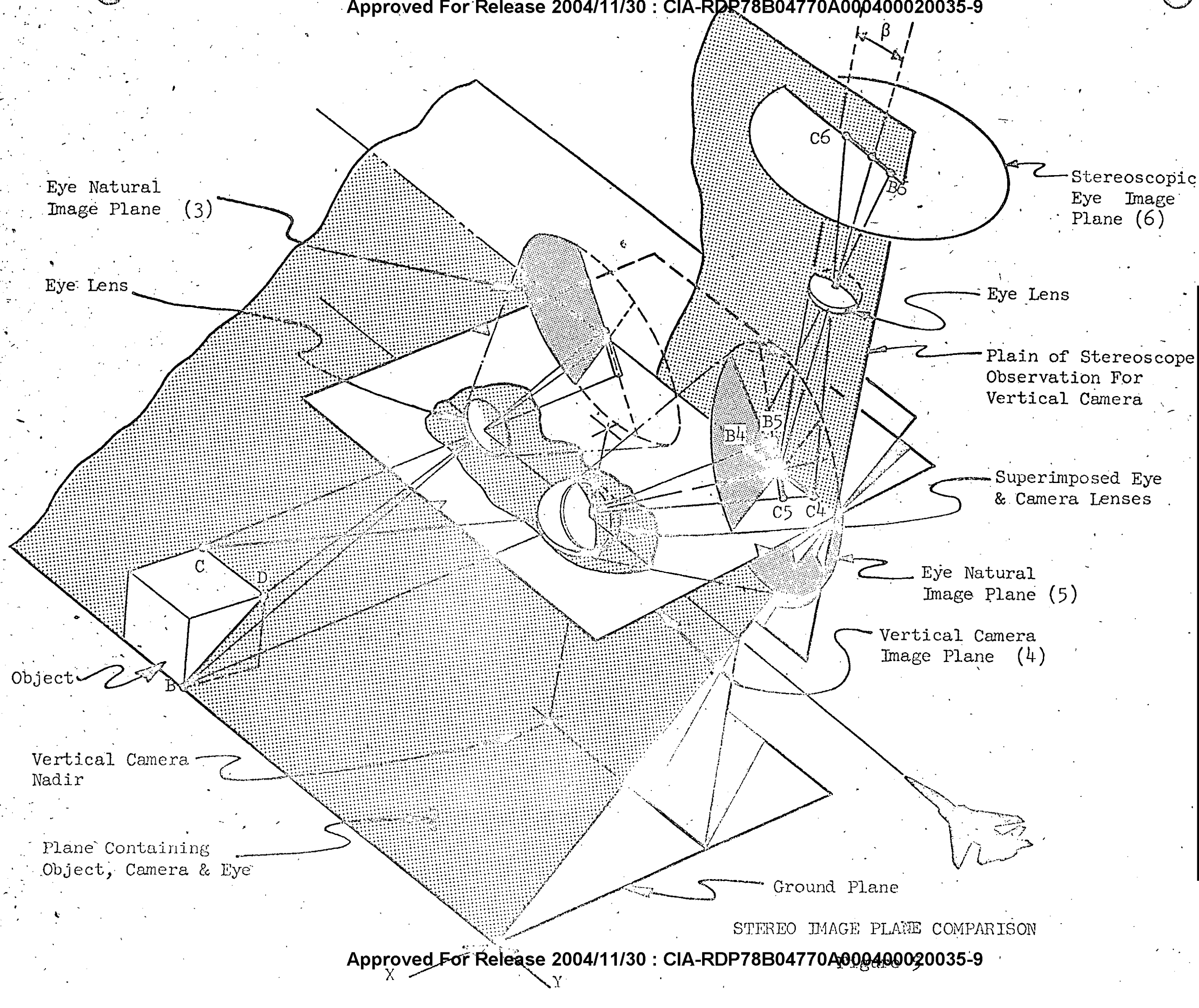

STEREO IMAGE PLANE COMPARISON

Figure 5

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However, the actual image viewed in the stereoscope lies in Plane (6). Image plane (6) is developed from Plane (4), which is the camera film. Object depth multiplication will result but will be distorted because of the inaccurate transmission of the angular relationships of the object image rays as they pass through the various coordinate transformations. The magnitude of these distortions is a direct function of the size of the angular disparities between image planes (4), (5), and (6). These angles are a function of camera image overlap which is in turn a function of camera area of view and focal length. Serial frame vertical camera Stereoscopic Observation Geometric Distortion is therefore directly related to the angle made by the object to the camera axis.

PAN cameras however exhibit a different distortion characteristic because of its cylindrical image plane, whose axis is aligned with the "Y" image coordinate. The radius of this cylinder is centered at the camera lens and produces the geometric effect of the camera always being directed in elevation to all objects. Thus, the camera produces the same image geometry as the eye, about this axis. Furthermore the normal position of the stereoscope optics, relative to the film, allows the stereoscopic eye image plane to be nearly parallel to the camera image about the "Y" axis. Thus Stereoscopic Observation Distortion lies almost entirely in the "X" coordinate of panoramic photography, being inversely proportional to the position of the object image from the photograph margin and the focal length of the camera.

Selection of Test Imagery

The test imagery was selected based upon the preceding analysis. The major portion of the experimental tests were conducted using low altitude imagery taken with a 1-3/4" focal length vertical serial frame camera and a 3 inch PAN camera. In order to complete the spectrum of the test, high altitude photography taken with an 18 inch PAN camera was also used. These films are further identified by Figure 6.

In all cases the imagery was searched for targets wich would exhibit varying orders of stereo distortion. Large cities were found to contain a generous selection of object sizes, shapes, and positions relative to nadir. Simulated jungle terrain, with swamps, canals, trees, brush, huts, etc. was also examined to complete the spectrum of targetry.

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FILM SAMPLE	SENSOR	ALT.	SUBJECT MATTER	APPENDIX
1.	18" PAN	38,000 FT.	NEW YORK CITY	II
2.	3.15" PAN	1,000 FT.	COLUMBUS, OHIO	III
3.	1.75" VERT.	460 FT.	SIMULATED VIETNAM	IV

NOTE: Copies of the test imagery are attached to the Appendix as noted.

FIGURE 6. LIST OF TEST IMAGERY

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Determination of Eyepiece Adjustment Procedure

The zoom anamorphic eyepiece can be considered as an ordinary zoom lens except that magnification changes occur only on one coordinate. Images viewed through the eyepiece can be stretched, vertically, diagonally, or through any oblique angle, by proper rotation of the stretch axis adjustment ring (see Figure 2.). The stretch range is from 1 X to 2.2 X, set by a similar zoom power adjustment ring. Both the zoom and stretch angle controls are calibrated.

By observation it can be seen from Figure 5, that the geometry of depth multiplication distortion and stereoscopic observation geometric distortion is complex. This is the consequence of the distortion of the angular relationships of image rays, produced as a result of the various image planes already defined.

Obviously a single axis linear image correction can not produce precisely the desired image coordinate modificaton. However, the intent of the anamorphic zoom eyepiece application is not to obtain a perfect image, but rather the recovery of otherwise unuseable stereo imagery. Thus, if sufficient distortion can be removed to allow stereo fusion in a significant number of cases, then the use of these eyepieces could be recommended for the SCV. Since this criterion is so highly subjective, trial observation by experienced observers was considered to be the only realistic method of evaluation.

The controls of the anamorphic zoom eyepiece were set by observation, using rules based upon the observed image situation.

They were as follows:

1. The nadir of the image was determined by observing, in each image separately, the direction of projection of vertical objects. The axis of maximum distortion was assumed to be aligned with a line passing through the image nadir and the object of interest in vertical photography, and along the photographic X coordinate in PAN photography.
2. The stretch axis of the eyepiece was aligned by moving the zoom control in and out, and rotating the axis control until the stretch appeared aligned as desired. This was done independently for each eye.

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3. The amount of stretch was determined visually by careful attention to the apparent stereo image geometry.
4. Although image shrinkage was the actual correction required, stretch correction was used because the eyepieces have no provisions for image shrinkage. (Although it appears intuitive that the effect of shrinkage could be achieved by rotating the stretch coordinate 90 degrees and expanding, it was found to be very troublesome. Such action required a compensating zoom of conjugate image optics, to maintain proper scale relationships. The resulting adjustment procedures became involved and unhandy).
5. If, after the application of rules (1) through (4) no beneficial result was obtained, the conjugates were observed monocularily then binocularily and stretch applied on the basis of what was seen.

Conduction of the Experiment

A pair of zoom anamorphic eyepieces was installed on SCV Prototype #1 located in the AGC Mock-Up at [redacted] This installation is shown in Figure 7. The test film was selected from the files of the RA5C Flight Test Program. Two experienced Photo Interpreters and an optical system engineer evaluated and discussed the effect of the eyepieces upon the imagery involved, and its potential application to the work performed on the SCV. This team used the experimental set-up for a period of two days.

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IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

No image situation could be found in the test photography for which the anamorphic eyepiece enabled the operator to recover otherwise unuseable stereo objects. Low altitude and high altitude PAN and serial frame photography was examined at 6X and 24X magnification. The results of depth and observation geometric distortions were evident where predicted.

In serial frame photography, where the distortions are two dimensional, the stereo fusion produced the usual three dimensional stereo distortions. For example, tall buildings, located near the edges of the photographs did not appear to be rectangular or vertical to their local terrain. The attempted application of the linear, single axis correction provided by the zoom anamorphic eyepieces only tended to increase the distortion. Film Number 3 (Figure 6.) was given particular attention because the subject matter represented imagery which was at the limit of the "eye-brain", to stereo fuse. The height of objects in this imagery was greatly accentuated, and certain objects could not be fused by any of the experimenters. Although it was obvious what image dimensions needed to be modified to enhance the probability of stereo fusion, the zoom anamorphic corrections always appeared to be inadequate. For cases where stereo fusion could be obtained in the zero correction setting (1X), subsequent attempts to trim and improve the image by adding anamorphic zoom, degraded the image.

The anamorphic zoom eyepiece did provide a type of image improvement in short focal length, low altitude PAN photography, represented by Film Number 2 (Figure 6). All objects in this imagery could be stereo fused using the unaided stereo system. However, tall objects, lying in the 30 degree to 50 degree (estimated) PAN scan angle field, appeared to be tipped toward the viewer, in referance to their local ground plane. It was found that this object "tip", could be removed by applying stretch along the "X" axis coordinate of each conjugate pair. This effect was in good agreement with the graphic analysis which predicted that PAN imagery would contain less complex geometric image distortion than serial frame photography. Thus, the simple correction provided by the zoom eyepieces was more effective.

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High altitude, long focal length PAN photography presented so little geometric distortion (Film Number 1, Figure 6), that there was not need for any image geometry correction.

Optically, the zoom anamorphic eyepiece reduced the object field at the eyepiece, and the light transmission of the over-all stereo system. Resolution was also degraded as a function of anamorphic zoom, particularly in one eyepiece. Time did not permit the measurement of these factors as it was felt that the factors pertaining to the improvement of the PI function were more important at this time.

The zoom anamorphic eyepieces were not designed to be used with the SCV, therefore certain mechanical and control inconveniences were evident. The eyepieces could not be locked to the SCV optics so they were free to pivot, obviating the use of the control indexes. The adjustment of stretch and stretch direction controls was a two handed operation for the same reason. Individually the eyepieces were sturdy, compact, and well constructed. The mechanical deficiencies noted were primarily the result of the application, and not the intrinsic design of the eyepieces.

Under certain circumstances the zoom anamorphic eyepieces could be useful for target identification tasks. However, for most of the PI functions, performed on the SCV the existence of stereo image distortion presents no hindrance. Adding four seldom needed controls to the stereo optic system would automatically increase the difficulty of doing routine stereo tasks and thereby reduce the overall effectiveness of the SCV.

The optical and mechanical deficiencies noted in the application of the eyepieces were such that they probably could be corrected by routine engineering refinement. The standardized configuration of the input-output fittings would make these eyepieces adaptable to most optical equipment and therefore their use should not be restricted to the SCV. Usefulness would probably be extended by providing image shrinkage as well as stretch.

Recommendations

The process of human stereo vision and the effects introduced upon it by the distortions of various optical systems, is a complex subject. The final evaluation of any new device, intended to improve the performance of stereo equipment, rests with

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the subjective opinion of human operators. The recommendations of this investigation are:

1. The zoom anamorphic eyepiece not be considered further at this time for incorporation into the SCV.

2. The present zoom anamorphic eyepiece be given further evaluation for application to equipment involved with highly detailed stereo analysis of imagery.

3. An analysis be conducted to determine if it would be practical to develop a new zoom anamorphic eyepiece whose correction would more nearly match the geometric error functions produced by typical reconnaissance collection - viewing systems for potential future use with the SCV.

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APPENDIX I.

DERIVATION OF THE IMAGE EXPANSION PRODUCED BY THE ZOOM ANAMORPHIC EYEPIECE

Given a square input image (A, B, C, D), determine the position of any point P (X, Y) in that image after being subjected to an anamorphic zoom of magnitude (a) in the x coordinate of a coordinate system x, y; rotated to an angle Θ relative to the input coordinate system X, Y.

The geometry of this situation is shown in Figure A, and defined as:

X, Y = Original image coordinate system
x, y = Coordinates of zoom anamorphic eyepiece, where x is the stretch coordinate
Θ = Angular relationship of coordinate system x, y to X, Y.
P = Any point on the input image.
P_s = The position of point P after anamorphic zoom.
a = The amount (power) of zoom magnification.

A,B,C,D = Bounds of input image.
A_s, B_s, C_s, D_s = Bounds of input image after subjection to anamorphic zoom.

Referring to Figure B, an enlargement of Figure A, the following derivation is based upon:

1. Line P_1 P_s is the line followed by point P as the power of the anamorpic zoom is raised from unity to "a".

2. Since zoom lies only in the x coordinate, line P, P_s will be parallel to line O, x.

3. Line P, E is parallel to coordinate O, X by definition

4. Line P, D lies perpendicular to coordinate O, x by definition.

5. $\therefore \Theta = \Theta_1 = \Theta_2$

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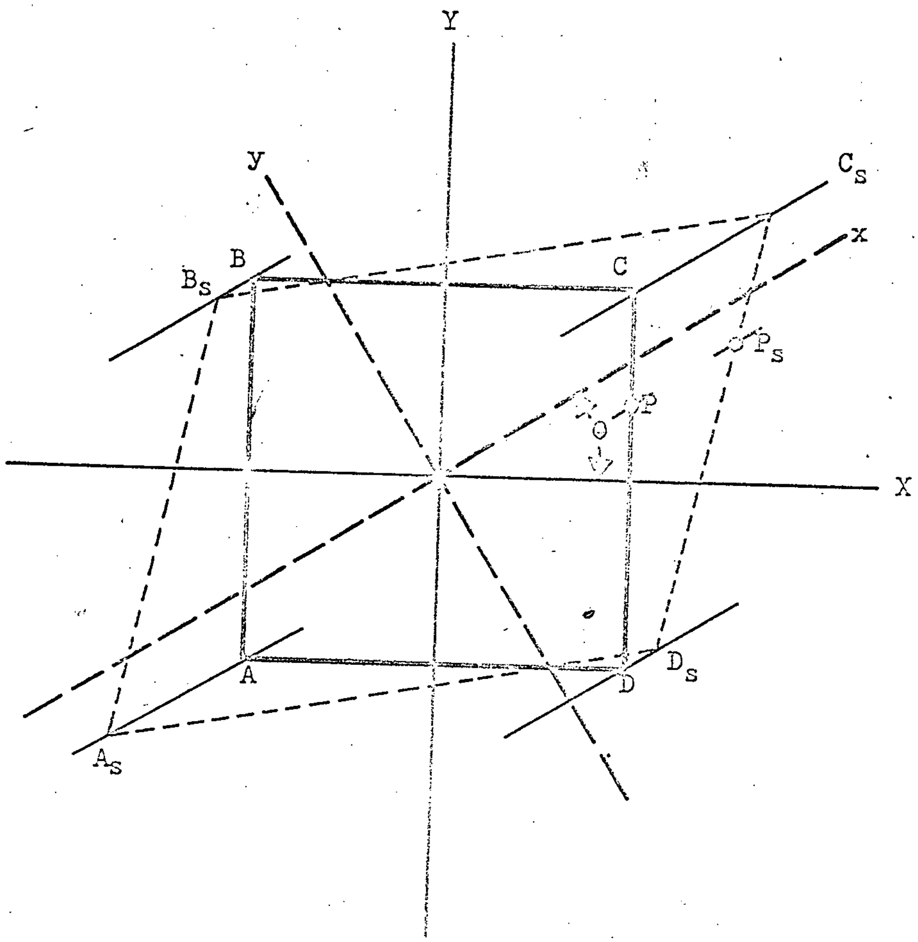

GEOMETRY OF ANAMORPHIC ZOOM

FIGURE A.

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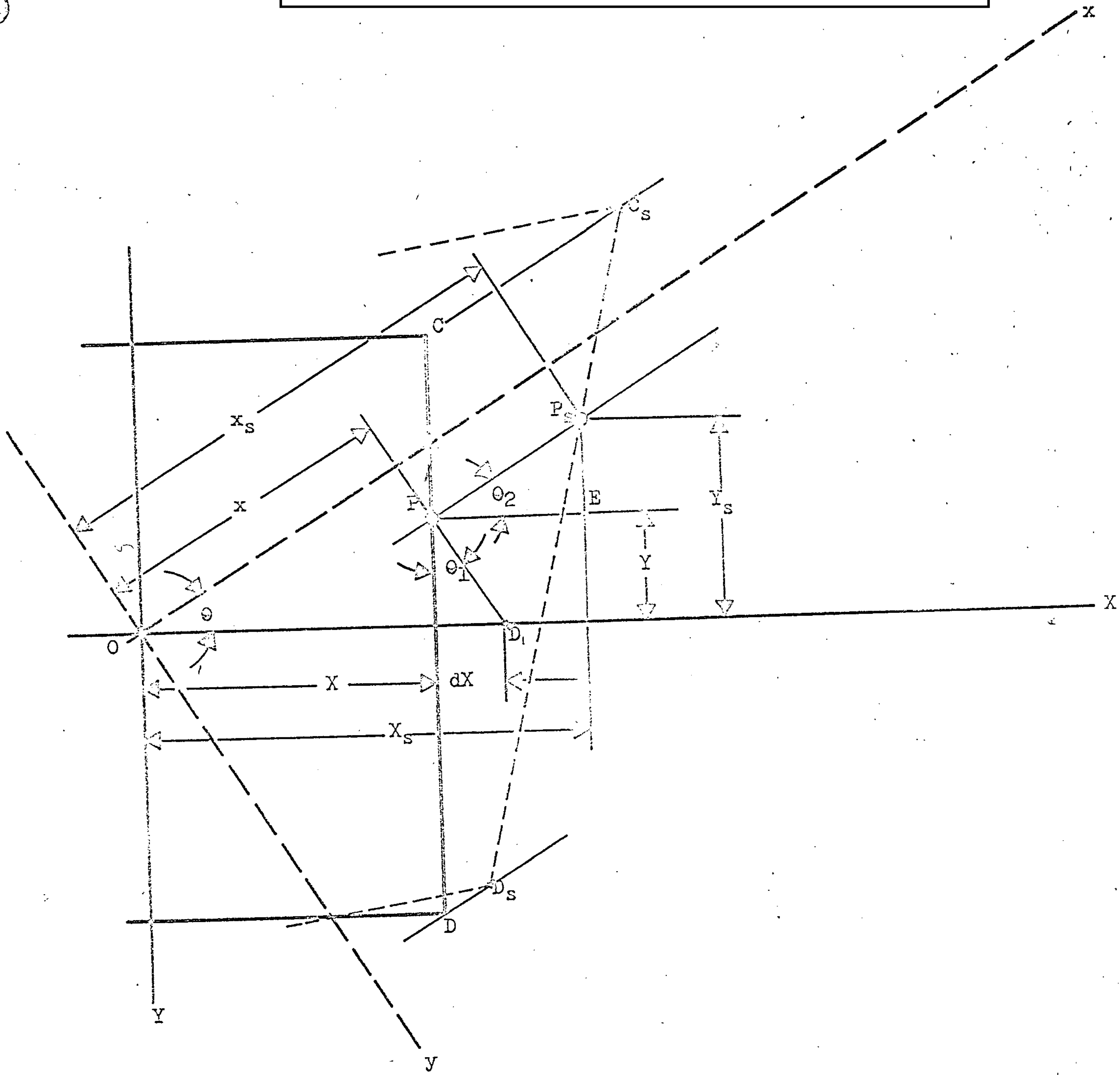

ANAMORPHIC ZOOM GEOMETRY DERIVATION DIAGRAM

FIGURE B.

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The action of any anamorphic zoom, lying totally in the x coordinate of the x, y coordinate system, upon any point P lying in the X, Y coordinate system, is therefore derivation as follows:

From Figure B:

$$dX = Y \tan \Theta_1$$

$$\cos \Theta = \frac{x}{X+dX} = \frac{x}{X+Y \tan \Theta}$$

$$x = (X + Y \tan \Theta) \cos \Theta$$

From Figure B:

$$\cos \Theta_2 = \frac{X_s - X}{x_s - x}, \quad X_s - X = (x_s - x)(\cos \Theta), \quad X_s = (x_s - x) \cos \Theta + X$$

By definition:

$$x_s = a\,x$$

By manipulation:

$$X_s = (a\,x - x) \cos \Theta + X$$

$$X_s = x\,(a - 1) \cos \Theta + X$$

$$X_s = (X + Y \tan \Theta)(\cos \Theta)\,(a - 1) \cos \Theta + X$$

$$X_s = (X + Y \tan \Theta)(\cos \Theta)^2\,(a - 1) + X$$

Using identity $\sin A = \cos A \tan A$:

$$X_s = X(\cos \Theta)^2\,(a - 1) + Y\,(\tan \Theta)(\cos \Theta)^2\,(a - 1) + X$$

$$X_s = X(\cos \Theta)^2\,(a - 1) + Y\,(\sin \Theta)(\cos \Theta)\,(a - 1) + X$$

(1) $$X_s = (a - 1)(\cos \Theta)\,\left[X(\cos \Theta) + Y(\sin \Theta)\right] + X$$

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From Figure B:

$$Y_s - Y = (x_s - x) \sin \Theta_2$$

$$Y_s = (x_s - x) \sin \Theta + Y$$

By definition:

$$x_s = a\,x$$

By manipulation:

$$Y_s = (a\,x - x) \sin \Theta + Y$$

$$Y_s = (a - 1)\,x \sin \Theta + Y$$

$$Y_s = (a - 1)\,(X + Y \tan \Theta)\,(\cos \Theta)\,(\sin \Theta) + Y$$

$$Y_s = (a-1)(\cos \Theta)(\sin \Theta)\,X + (a-1)(\cos \Theta)(\sin \Theta)(\tan \Theta)\,Y + Y$$

$$Y_s = (a-1)(\cos \Theta)(\sin \Theta)\,X + (a-1)(\sin \Theta)^2\,Y + Y$$

(2) $$Y_s = (a-1)(\sin \Theta)\left[X \cos \Theta + Y \sin \Theta\right] + Y$$

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